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Preliminary study on streamlined design of longitudinal profile of high-speed train head shape

Xinwen YANG[a,]*, Jielong JIN[b], Guangtian SHI[b]

[a]*Key Laboratory of Road and Traffic Engineering of the Ministry of Education, Tongji University, 4800 Cao-an Road,Shanghai 201804, China*
[b]*School of Mechatronic Engineering, Lanzhou Jiaotong University, 88 An-ning West Road, Lanzhou 730070, China*

Abstract

* The effect of high-speed train head shape on its aerodynamic performance is very important. In order to prove the effect of longitudinal profile shape of train head on aerodynamic performance, using CFD method, a two dimension model is developed to investigate outer flow field of high speed train head. Three types of train head profile schemes are calculated. The effects of longitudinal profile shape of high speed train head on aerodynamic performance are analyzed. The results show that different head profile curves cause different surface pressure distributions of body, different airflow velocities of outer flow field and different turbulent distributions. If the longitudinal profile shape of train head is spindle and streamline length of train head is 8m, aerodynamic drag of the train will well reduce.

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Keywords: High speed train; Streamlined design; Aerodynamics performance; Train aerodynamics

1. Introduction

During the last two decades the China high-speed railway (HSR) network has become an interesting alternative to airplanes what belongs short to medium distances up to 1000km. The average velocity reached on some connections in China exceeds 300 km/h, and high speed railway achieves travel times even lower as that of the corresponding flight connection. However the increase in velocity is accompanied by aerodynamic phenomena which are only of minor importance in standard lines with running speeds up to 300 km/h. High speed train's shape design, especially its head modelling design, has great influence on the aesthetic function and aerodynamic

* Corresponding author. Tel.: +86-21- 6958-3659; fax: +86-21-6958-9880
E-mail address: xinwenyang@tongji.edu.cn

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performance. The train's head design must meet to both artistic and superior aerodynamics requirement, which needs the support from the intersecting subject of the industrial design and the aerodynamics. The head shapes of high-speed train with optimal synthetic aerodynamic performance can efficiently reduce the influence of the aerodynamic phenomena on the train operation and the environment.

Aerodynamic performance of high-speed train has a close relationship with the head shape of the train, and the whole train aerodynamic performance is directly affected by itself streamlined shape and inclination angle [1]. In order to reduce air drag and improve its aerodynamic performance, people usually pursue optimal shape of high speed train. The optimization process of train shape is a continue increasing process with train' speed, and also is an investigating in-depth process of train aerodynamics. The relationship between aerodynamic performance and head shape of high speed train is described, and the effects of train head shape on aerodynamic performance are studied, and aerodynamic design methods and guidelines of train head are given [2]. The effect of high-speed train shape on its aerodynamic performance is investigated, and the current trends of the head shape of high-speed train are introduced in all worlds [3].Using CFD software Fluent, the influence of the train head shape on the rear flow field had analyzed, and the train safety distance moved was obtained [4]. The head streamlined design can significantly improve the aerodynamic characteristics of the train, and effectively reduce more than 60% running air resistance than the traditional train at the same speed. At the same time, it also can reduce the pressure transient in tunnel and aerodynamic noise of the train [5]. The effect of different longitudinal profile of train head on the air resistance and the meeting pressure wave was studied. The results show that in order to simultaneously reduce the air resistance and passes shock, train shape design needs to be overall evaluated [6]. Effect of shape of train nose on compression wave generated by train entering tunnel had studied [7]. In French, a comprehensive test method was developed to investigate aerodynamic noise mechanism of TGV high speed train, through the noise beam measurement, laser doppler velocimeter, aerodynamics digital simulation and wind tunnel test, which is beneficial to optimize vehicle parts design to achieve the noise reduction [8]. Using multi-body dynamics theory and fluid-structure coupling method, the near surface near field aerodynamic noise of high-speed train's head surface are calculated [9].

Usually, the research on train head feature modeling mainly focuses on the following [10]:

① Longitudinal section streamline shape of train head;

② Lateral section shape of train head;

③ Lengths and slenderness ratio of head streamline part;

④ Flow guided plate and side baffle plate beneath the vehicle.

Therefore, in this paper, the effect of the longitudinal profile shape change of train head on aerodynamics performances is investigated. Some solutions analysis of longitudinal profile of train head are carried out.

2. Computational model

2.1. Flow governing equations

Base on law of mass conservation and theorem of momentum, The governing Navier-Stokes equations of the present flow, which is considered incompressible, may be expressed as follows[11]:

Continuity equation

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

Momentum equation

$$\rho\left(\frac{\partial u_i}{\partial t} + \frac{\partial\left(u_j u_i\right)}{\partial x_j}\right) = \rho v \frac{\partial}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{\partial p}{\partial x_i} \tag{2}$$

where ρ is the density of flow fluid; the turbulent viscosity, ρv, depends on the flow and is calculated from the specific turbulence model.

2.2. Turbulence models

The effects of turbulence on the flow were implemented via k-ε turbulence models [11]:

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_i}\left[\left(\mu_1+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+\mu_t\frac{\partial u_j}{\partial x_i}\left(\frac{\partial u_j}{\partial x_i}+\frac{\partial u_i}{\partial x_j}\right)-\rho\varepsilon \tag{3}$$

$$\frac{\partial(\rho \varepsilon)}{\partial t}+\frac{\partial}{\partial x_i}(\rho \varepsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu_1+\frac{\mu_t}{\sigma_k}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+C_1\mu_t\frac{\varepsilon}{k}\frac{\partial u_j}{\partial x_i}\left(\frac{\partial u_j}{\partial x_i}+\frac{\partial u_i}{\partial x_j}\right)-C_2\rho\frac{\varepsilon^2}{k}$$

(4)

$$\mu_t=C_\mu\frac{\rho k^2}{\varepsilon} \tag{5}$$

where k, turbulence kinetic energy, ε, turbulence dissipation ratio, μ_1, the laminar viscosity, μ_t, the turbulent viscosity, and σ_k=1.0， σ_ε=1.0， C_1=1.44， C_2=1.92 , and $C\mu$=0.09 are model constants.

2.3. Flow domain of train head and boundary conditions

According to high speed train's head longitudinal profile characteristic, a two dimensional (2D) model is developed to study the influence of the head longitudinal profile on aerodynamics behavior of high-speed train. A 2D model of outer domain around a train head is shown in Fig.1. The length of the train head is 12m, and the height of the train head is 3.8m. According to train head's configuration size, the flow field domain around the train head is: The length is 60m, and the height is 15m, and the inlet is located in 24m apart from the train head, the outlet is located in 24m apart from the train rear, the boundary distance upper the train is 7.6m, the lower boundary distance is 3.6m. The flow field size has guaranteed enough computation precision. The medium of flow field is the normal temperature air.

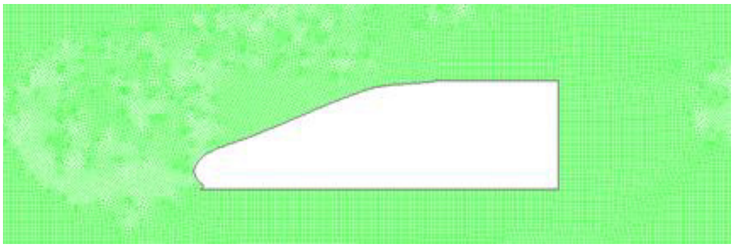


Fig.1. Flow field around the train head longitudinal profile domain

The boundary condition is as follows:

(1) The inlet boundary condition: the inlet velocity is 280km/h, and turbulence dissipation ratio k and turbulence kinetic energy ε , are 0.1;

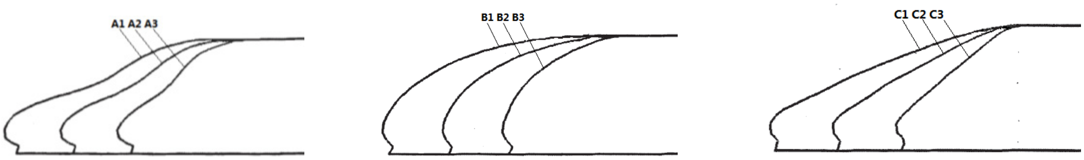
(2) The outlet boundary condition: the outlet pressure is 0Pa, and the rear turbulence dissipation ratio k and turbulence kinetic energy ε , are 1;

(3) In order to consider the effect of the ground on the train drag and the lifting force, the field ground is set to slip wall boundary. Body surface and upper boundary are set to fixed wall.

In addition, the air density, ρ =1.225kg/m^3, air viscosity is 1.7894×10^{-5} kg/(m·s), initial calculated temperature is 300K, initial atmospheric pressure is 1.01325×10^{5}Pa.

3. The numerical design schemes

Because the train longitudinal section profile had decided the overall trend of train shape along the train length, these are main control line of the train shape, whose shape and length had a significant effect on train's aerodynamic performance. In the present paper, main discussion contents are: assume that the width and height of the train head are certain, under the invariable situation of the upwind side project areas, three groups of numerical design schemes are proposed in Fig.2. Group A is the double arch profile of train head, Group B is the single arch profile of train head, and Group C is the spindle profile of train head. There are three types of shape in each group. Base on the change of length and streamline curve of the train head, they are: (1) A1, A2, and A3; (2) B1, B2, and B3; (3) C1, C2, and C3. The streamline length in each group is 8m, 6m, and 4m, respectively.



(A) (B) (C)

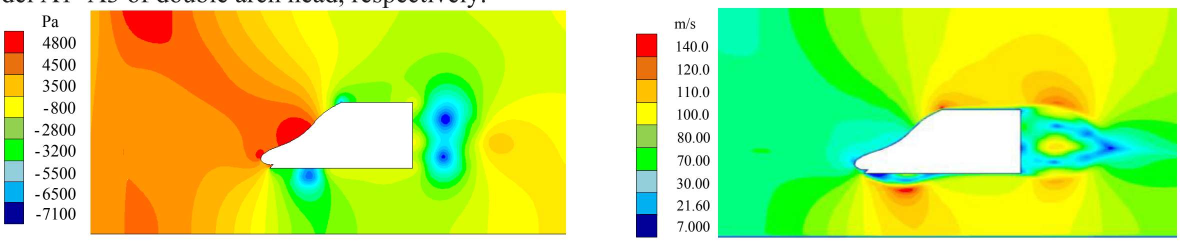
Fig.2. Schematic of the longitudinal control line of high-speed train head

4. Result and discussion

In order to probe the effect of three groups head design on aerodynamics performance of high speed train, some simulations are carried out to obtain body surface pressure distribution, the flow field stream velocity of outside flow field, and turbulence regional distribution relevance.

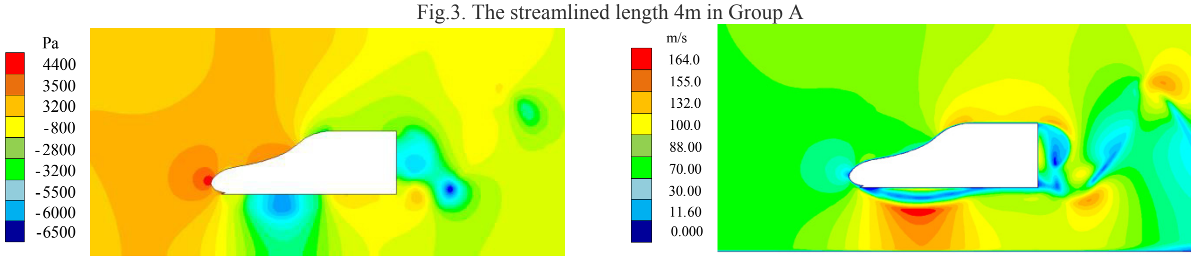
4.1. double arch-shaped head

The double arch-shaped head is one kind of modelling used generally in high speed train. In China, high speed train (CRH2) had adopted this shape. The double arch head both maintains the automobile streamlined body and to be possible to guarantee the locomotive cab space highly which had the enough inclination angle with the windshield glass. This design made driver's vision scope not to be affected, and the driving interior space not to be constrained. But it can produce the air current hinder between the vehicles first arch and the second arch, so it has big drags in front of the window. Fig.3~Fig.5 are the pressure distribution and the flow speed contour of model A1~A3 of double arch head, respectively.



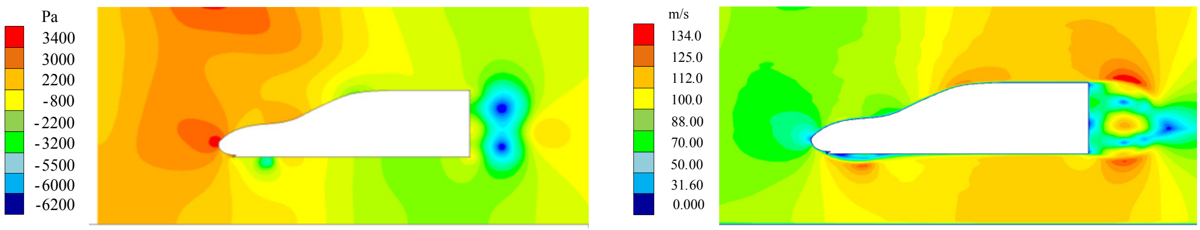
(a) Pressure distribution (b) Flow velocity contour map

Fig.3. The streamlined length 4m in Group A



(a) Pressure distribution (b) Flow velocity contour map

Fig.4. The streamlined length 6m in Group A



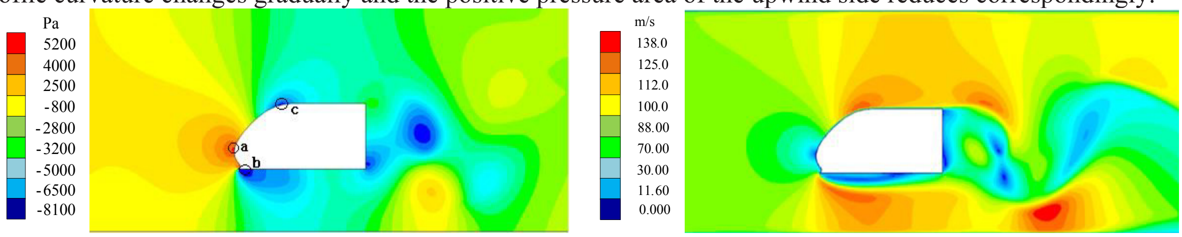
(a) Pressure distribution (b) Flow velocity contour map

Fig.5. The streamlined length 8m in Group A

Through the comparison we may see, the highest positive pressure of the fore concentrates in most front end of upwind side. The colour progressive changes in the picture have reflected the pressure and flow velocity change from high to low. With the increase of a train head length from 4m to 8m, the surface pressure change of a train head is gradually small. The highest positive pressure of upward side falls gradually from 4800Pa to 3400Pa, whereas the flow velocity does from 140m/s to 134m/s. This reduction is because air current outside the flow field adhered to stick cohere in the head surface, which is flatten out along with streamline head. In addition, the gradient change of the head section is small. Moreover, in model A1, A2, and A3, the isopiestic distributed rules are extremely similar: the centralism area of the biggest positive pressure is firstly located in the vehicle nose spot, secondly in arch interface point. The intersection point between vehicle nose and the air deflector will produce two obvious air currents. This similarity indicated flow field the distribution of the train head is biggest.

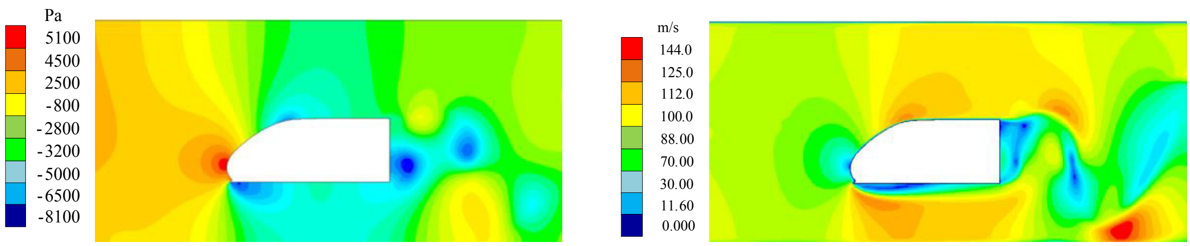
4.2. single arch-shaped head

The longitudinal profile of single arch-shaped head has absorbed the inspiration from the water-drop shape. This profile curvature change is very small and the curve profile of the upwind side is similar to half ellipsoid body. When the air flow meets at the fore end of the head, the wind drag may be reduced effectively. The pressure distribution and the flow velocity contour of single arch-shaped head are shown in Fig.6~8. It can be seen from these pictures that maximum of the upwind side pressure arrives 5220Pa, whereas pressure intensity maintains continuously transient from point ***a*** to point ***b***. In addition, with the increase of train head length, the profile curvature changes gradually and the positive pressure area of the upwind side reduces correspondingly.



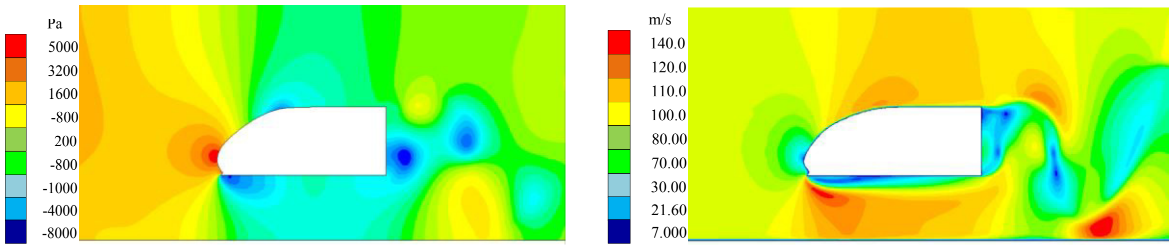
(a) Pressure distribution (b) Flow velocity contour map

Fig.6. The streamlined length 4m in Group B



(a) Pressure distribution (b) Flow velocity contour map

Fig.7. The streamlined length 6m in Group B

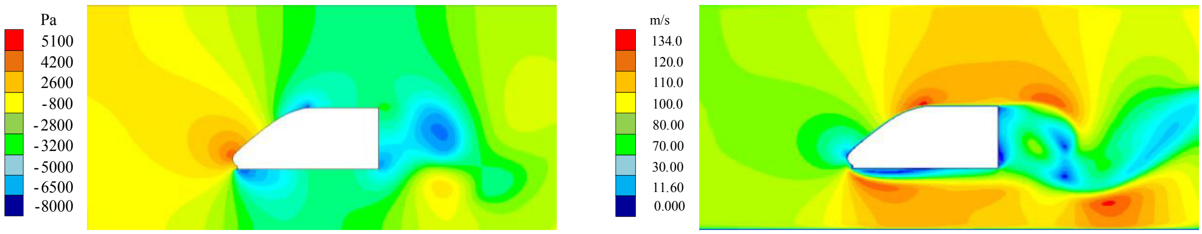


(a) Pressure distribution (b) Flow velocity contour map

Fig.8. The streamlined length 8m in Group B

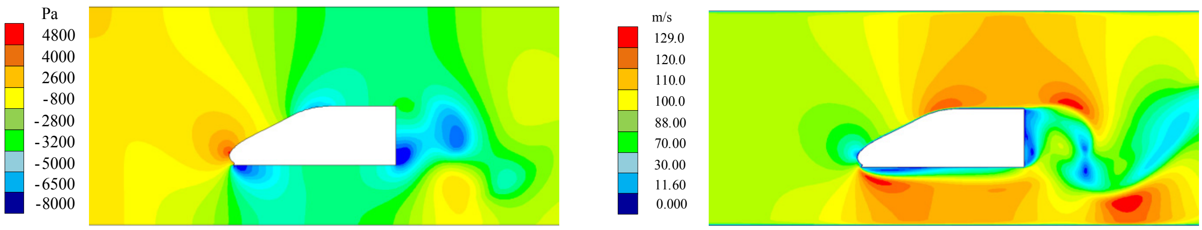
4.3 spindle-shaped head

For the spindle-shaped head profile, there is an incline straight line on upwind side. This design will make greatly upwind side area to reduce. When the air flow meet at train fore, it will flow over from the vehicle top as well as the both sides, and avoid hinders which the arch-shaped head produces due to large area of upwind side. The pressure distribution and the flow velocity contour of spindle-shaped head of a train are shown in Figure9-11. It can be seen that maximum of the upwind side pressure arrives from 5100Pa to 4700Pa, and the biggest negative pressure area will reduce. In addition, with the increase of the train head length, the dispersal area of the low pressure region in the upwind side will increase gradually. When the head length of a train is increased to 8m, the upwind side will appear the wide negative pressure band.



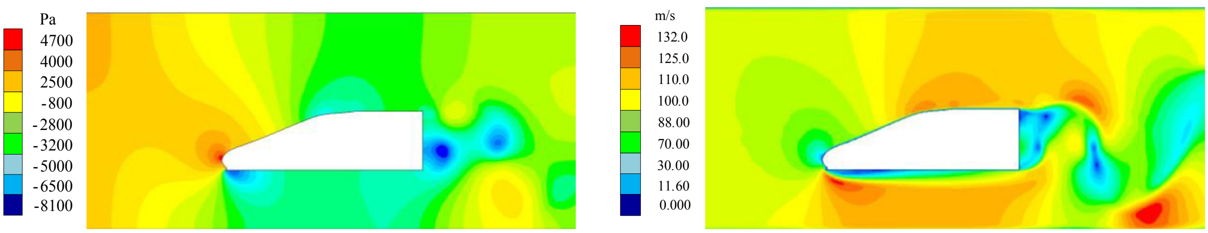
(a) Pressure distribution (b) Flow velocity contour map

Fig.9. The streamlined length 4m in Group C



(a) Pressure distribution (b) Flow velocity contour map

Fig.10. The streamlined length 6m in Group C



(a) Pressure distribution (b) Flow velocity contour map

Fig.11. The streamlined length 8m in Group C

4.4 Three-group program calculation results

After the above analysis, the aerodynamics performance of the head in model C1 is best in three groups of design. Fig.12 illustrated the surface static pressure of the train head in model C1 distribute around the head. Fig.13 has indicated drain turbulent distribution of the flow field around the head in model C1.

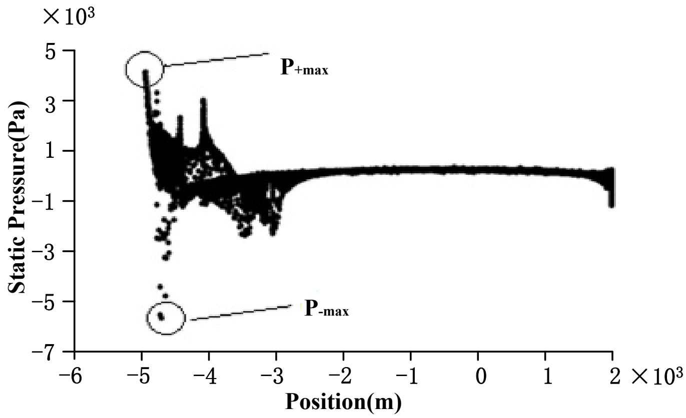


Fig.12. C1 program trains the front surface static pressure distribution

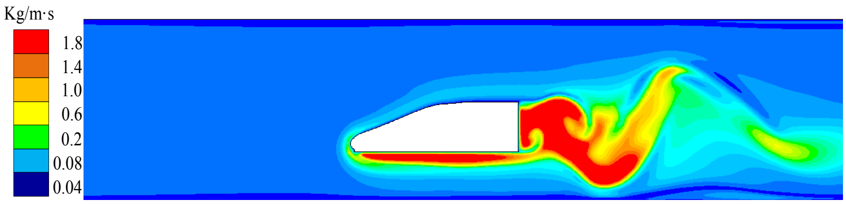


Fig.13. C1 train head drain turbulent cloud map

5. Conclusion

In this paper, the longitudinal section control line of high-speed train head has been investigation through numerical simulation. It can be seen that numerical simulation method is very good way in studying aerodynamic performance of train shape design. Some conclusions are obtained as follow:

(1) This is a very economic technical route to study the scheme analysis, model repeated modification, the best design solution through the CFD numerical simulation.

(2) The longitudinal profile streamline design of a high speed train has the tremendous influence on the train aerodynamics performance. It can be concluded that the spindle-shaped profile of the train longitudinal section with streamline length 8m can reduce effectively aerodynamic drag.

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References

[1] Raghunathan, R.S., Kim, H.D., Setoguchi, T. (2002). Aerodynamics of high-speed railway train. *Progress in Aerospace Sciences*, *38*, 469-514.

[2] Tian, Hongqi (2007). *Train aerodynamics*. Beijing: China Railway Press.

[3] Chen, Xihong (1997). Appearance and development trend of high-speed train. *Electric Locomotive Technology*, *3*, 1-4.

[4] Wang, Dong-ping, Zhao, Wen-zhong, MA Si-qun (2007) . Application of CFD Numerical Simulation in High Speed Train Design. *Journal of the China Railway Society*, *29* (*5*), 55-59.

[5] Xu, Chen-xiao, Zhu, Heng-jun, Qi, Hong-yuan (2002). Conformal mapping-based analytical modeling on head shape of high-speed train. *Journal of the China Railway Society, 24* (*4*), 38-41.

[6] Zhang, Shu-guang (2009). *High-speed train design method*. Beijing: China Railway Press.

[7] Maeda T, Matsumura T, Iida M, Nakatani K, Uchida K (1993). Effect of shape of train nose on compression wave generated by train entering tunnel. In: *International Conference on Speedup Technology for Railway and Maglev Vehicles*, Yokohama, Japan.

[8] L.Guccia, et al (1997). Investigation on TGV high-speed train aerodynamics noise. *Foregin Rolling Stock*, 4:35-37.

[9] XIAO You-gang, KANG Zhi-cheng (2008). Numerical prediction of aerodynamic noise radiated from high speed train head surface.*Journal of Central South University*, *39*(*6*):1267-1272.

[10] Raghu S. Raghunathana, H.-D. Kimb,*, T. Setoguchic (2002). Aerodynamics of high-speed railway train. *Progress in Aerospace Sciences ,38*:469 – 514

[11] WU Zi-niu (2007). *Aerodynamics*. Beijing:Tsinghua University Press.

[12] WANG Fu-jun (2004). *Computational fluid dynamics analysis —Principle and application of CFD software*. Beijing:Tsinghua University Press.